Kinematic Comparison of the BiCaal Orthosis and the Rigid Polypropylene Orthosis in Stroke Patients

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A rigid ankle-foot orthosis (AFO) is commonly applied to the lower extremity to stabilize the limb and correct gait deviations caused by neuromuscular disease. The rigid design is useful in correcting plantar flexion deformities resulting from moderate or severe spasticity or to stabilize the ankle of a flaccid limb. In addition to sagittal plane stability a rigid ankle-foot orthosis is capable of supporting the ankle in the frontal plane, correcting existing varus or valgus. In the past the bichannel adjustable ankle locking (BiCAAL) orthosis has been the traditional and most commonly used orthosis with a rigid ankle design (Fig. 1). The adjustable double action joint mechanism enables the clinician to set the AFO in the optimal position.[1 7]

Widespread use of plastic polymers in lower extremity orthotics has occurred in the last decade.[8 12] Orthoses fabricated with these materials are lighter, more comfortable, and more cosmetic. The typical plastic AFO is flexible and allows more motion than the BiCAAL orthosis. It, therefore, is less effective in stabilizing the ankle and foot when rigid support is desired. Although rigid plastic AFOs are in use, their effectiveness is questionable because they still retain some flexibility and are not adjustable.

The purpose of this paper is to report on a kinemetric evaluation of the rigid polypropylene orthosis compared to true conventional metal BiCAAL design.

METHOD

Patients already fitted and accustomed to a BiCAAL AFO were fitted with a rigid ankle polypropylene AFO. Kinematic gait characteristics were studied to make an objective comparison of walking performance in the two orthoses.

EQUIPMENT AND INSTRUMENTATION

Orthoses

The rigid polypropylene AFO was custom fitted over a positive mold of the subject's leg. Conventional vacuum forming techniques were used to fabricate the orthosis from a sheet of polypropylene (Fig. 1).[9 10] Rigidity was obtained in two ways: by using a thick sheet of polypropylene,

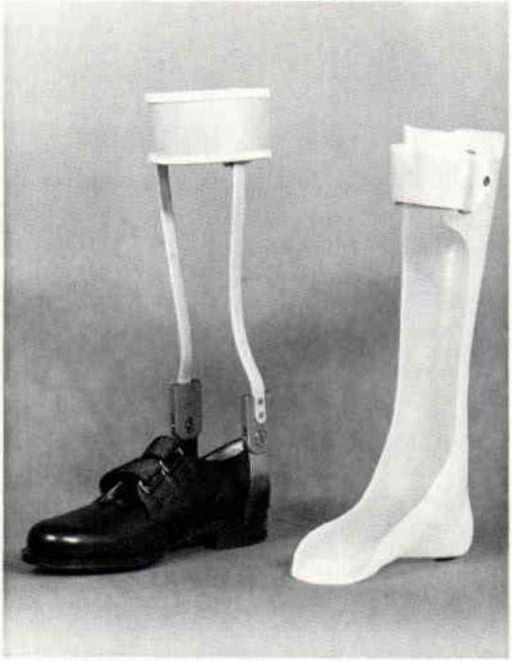

Fig. 1—The BiCaal and Rigid Ankle Polypropylene Orthosis.

and by extending the trim lines anteriorly at the ankle. Three-sixteenths inch polypropylene was used initially in contrast to the more commonly used ⅛ inch material used in most conventional orthoses. The medial and lateral trim lines were extended anteriorly to the apex of the malleoli to serve as supporting side struts. The footplate of the orthosis extended just proximal to the metatarsal heads.

The insertion of the polypropylene orthosis inside the shoe usually required a shoe size one-half size larger and the next width wider that previously worn. To eliminate the purchase of two pairs of shoes, once a shoe was fitted on the polypropylene side, an inlay was placed in the shoe of the second limb.

The ankle position of the polypropylene orthosis was set so that with the patient wearing a shoe with his normal heel height (1.3 to 1.9 cm), the tibia extended several degrees backwards from the vertical position. This slight plantar flexion position was chosen because patients with ankle instabililty secondary to paresis of the triceps surae generally walk in one of two abnormal gait patterns. In some, the tibia collapses forward during the stance phase and the ankle is excessively dorsi-flexed. There is compensatory knee flexion and greater than normal quadriceps contract is necessary to stabilize the knee. Most patients quickly learn a second gait pattern. The knee is purposefully hyperextended just after heel contact before significant limb loading occurs. Instead of excessive forward tibial rotation the tibia extends backward and the ankle is in plantar flexion. Because the patient's center of gravity passes anterior to the axis of the knee joint the knee is stabilized by the posterior joint capsule so excessive quadricaps activity is not required.

If an attempt is made to stabilize the tibia in the true vertical position with an orthosis there may be a tendency for the tibia to rotate either forwards or backwards against the shank cuff, since some ankle motion occurs within the orthosis. Because most patients perceive forward tibial rotation to be unstable, orthosis was positioned in slight plantar flexion to ensure the unstable tibia would always be thrust backward.

The BiCAAL AFO was of standard design.[1, 6] The ankle joints had anterior and posterior channels enabling adjustment of the ankle in the sagittal plane. The uprights were attached via a steel stirrup to an oxford style shoe containing a steel shank extending to the metatarsal heads (Fig. 1).

Foot Switch System and Level Walkway

An insole foot-switch system provided quantitative information about foot-floor contact patterns on both the involved and sound limbs.[13] The insole contained four switches; under the heel, great toe, and the heads of the first and fifth metatarsals. Each switch consisted of a Pressex® module which when compressed, completed a circuit. Each switch transmitted a different voltage for output on a strip chart recorder. Analysis of the combined output voltage enabled identification of the different combinations of weight bearing.

All foot-floor contact information was transmitted to a receiver by a radio telemetry system and recorded on analog tape and a visicorder. The most representative pattern of contact was determined for each subject and used for comparison as subjects walked in the rigid polypropylene and BiCAAL AFO's.

All walking was done on an indoor level 15 meter walkway. The middle six meter segment, with a light beam emitter to mark the patient's entry and exist at either end was used for data collection. The light beam triggered a signal superimposed on the foot switch record to enable a computation of gait velocity.

Electrogoniometers

Electrogoniometers described in a previous report[13] measured the ankle and knee rotation. The knee goniometer was positioned in front of the joint. It consisted of a double parallelogram linkage secured by cuffs above and below the knee. Joint rotation drove a potentiometer attached to the proximal arm of the linkage. This enabled direct measurement of knee position. Cables supported by an overhead track above the walkway transmitted the output.

The ankle electrogoniometer was constructed similarly to the knee goniometer. It was secured above and below the ankle joint and recorded the angular motion occurring between the tibia and foot in the sagittal plane.

PROCEDURE

Data from the foot switches and electrogoniometers was received during the middle six meters of the fifteen meter walkway. The first test session involved walking at free velocity in the BiCAAL AFO. One warm-up run was permitted.

A similar second test session using the rigid polypropylene orthosis was scheduled a minimum of two weeks after the fitting to allow the patient to become accustomed to the new orthosis. They were instructed to wear the new orthosis exclusively during this time.

Subjects

Each of the 17 hemiparetic patients selected for the study could walk safely in a prescribed BiCAAL AFO without the aid of a cane, crutch or walker and had worn the orthosis for an average of 28 months (range: 3 to 132 months) prior to fitting with the rigid polypropylene AFO. Their ages ranged from 23 to 70 years (mean: 53 years, Table 1). Each subject had unilateral hemiparesis of varying degrees, ten were right and seven were left hemiplegic. All

Table 1
PATIENT DATA

Subject	Sex	Age (Years)	Hemiparesis	Time Since Onset[a]	Time in BiCAAL AFO[b]
1	Female	70	Left	7	6
2	Male	60	Right	36	31
3	Male	53	Left	7	5
4	Male	63	Left	5 Years[b]	2.5
5	Male	53	Right	20	17
6	Male	43	Left	7	6
7	Male	53	Right	7	5
8	Female	55	Right	11 Years[b]	36
9	Male	23	Right	10	7
10	Female	30	Right	15	13
11	Male	65	Left	6	4
12	Female	64	Left		4
13	Male	61	Right	9	6
14	Female	57	Left	5	4
15	Female	58	Left	8.5 Years[b]	6.2 Years
16	Male	70	Right	8	4
17	Female	23	Right	3	3

[a]At time of testing, in months.
[b]Date of initial episode.

Table 2

Average Stride Characteristics Generated by Subjects as they Walked in the Polypropylene and BiCAAL AFO's at Free Cadence. N = 16[a]

Stride Characteristic	Polypropylene AFO		BiCAAL AFO	
Velocity (cm/sec)	57±	(34)	51±	(24)
Cadence (Steps/min)	80	(21)	77	(17)
Stride Length (meters)	.80	(.3)	.76	(.2)
(%) Normal Single Limb Support Time	49	(25)	51	(20)
(%) Gait Cycle Swing	39	(7)	48	(6)
(%) Gait Cycle Total Double Support Time	36	(13)	26	(7)
(%) Gait Cycle Initial Double Support Time	16	(5)	10	(5)
(%) Gait Cycle Terminal Double Support Time	21	(12)	16	(6)

[a]Subject 5 dropped out of study prior to second test session.

were able to follow instruction for participation in the study.

Ankle stability depends on the presence or absence of selective muscle strength, patterned motion, spasticity in the triceps surae, proprioception, tactile sensation and ankle range of motion. The participants were grouped according to their degree of spasticity to determine how this component of tibial control affected ankle position. Of the sixteen persons, five had moderate to severe plantar flexion spasticity. In these latter persons the orthosis was worn to stabilize the ankle and prevent excessive forwards or backwards ankle rotation.

RESULTS

Stride Characteristics

The average values for velocity, cadence, and stride length in the group did not differ when using the rigid polypropylene orthosis or the BiCAAL orthosis (Table 2). The average velocity in the rigid polypropylene AFO was 57±34 cm/sec and in the BiCAAL AFO 51±24 cm/sec. Stride lengths were .80±.30 meters in the polypropylene AFO and .76±.24 meters in the BiCAAL AFO. Cadence in the polypropylene AFO averaged 80± steps/minute and 77±17 steps/minute in the BiCAAL AFO.

There was a significant difference (P□.05) in the involved limb swing time. Expressed as a percent of the gait cycle it averaged 48±6 percent in the BiCAAL and 39±7 percent in the polypropylene AFO. No difference (P□.05) was found in the amount of time spend in single limb stance. Double support time, however was significantly greater (P□.05) with the rigid polypropylene AFO (36±13 percent of the gait cycle) than with ambulation in the BiCAAL AFO (26±7 percent of the gait cycle).

When the subgroups were compared, the degree of clinical plantar flexion spasticity had no consistent effect on the stride characteristics in either of the orthoses.

Knee and Ankle Joint Rotation

Both AFO's permitted some motion at the ankle (Figure 2). Similar ankle joint rotation patterns were noted for the two orthoses with the polypropylene AFO demonstrated a slightly greater flexion range throughout the gait cycle. At initial contact both orthoses were in plantar flexion with a gradual dorsiflexion deflection occurring in mid-stance and reaching a peak in terminal stance. A rapid increase in ankle plantar flexion occurred at the end of terminal stance after heel rise and continued throughout the swing phase of gait. Maximum plantar flexion occurred at initial contact. The only statistical difference (P□.05) in ankle posture between the two AFO's existed at toe-off. Ambulation in the rigid ankle polypropylene AFO yielded an average of 4±5 degrees of plantar flexion, while in the BiCAAL orthosis the average was 1±5 degrees of dorsiflexion.

Significant differences (P□.05) in the amount of knee motion occurring between

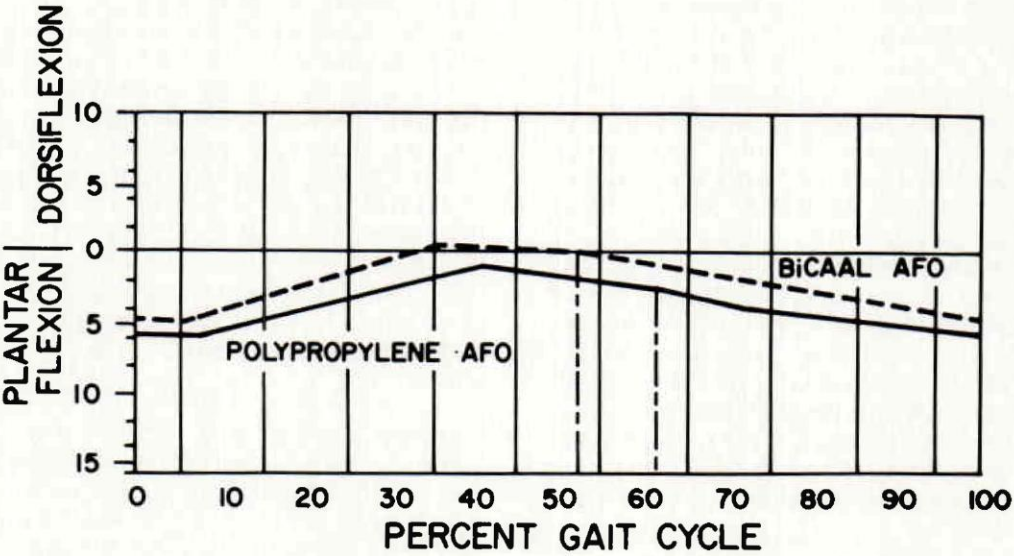

Fig. 2—The mean ankle joint position during free cadence walking with the polypropylene and BiCAAL AFO's.

ambulation in a polypropylene and a BiCAAL AFO were found at initial contact during free velocity walking. In the rigid ankle polypropylene AFO the participants demonstrated greater knee extension at initial contact (polypropylene AFO 6 ± 8 degrees of knee flexion, BiCAAL AFO 10 ± 7 degrees of knee flexion). A trend of more mean knee extension in the polypropylene AFO existed throughout the gait cycle although only statistically significant at initial contact.

Knee and ankle range of motion throughout the gait cycle were not influenced by the degree of clinical plantar flexion spasticity.

Foot-Floor Contact Patterns

The foot-floor contact patterns at initial contact were influenced by the degree of ankle plantar flexor spasticity and the type of orthosis. Fifteen of 16 subjects initially contacted the floor with the heel using the polypropylene AFO. While using the BiCAAL AFO only nine had normal heel first contact patterns. The differences were most apparent in the group of patients with excessive plantar flexion spasticity. Four of five subjects with moderate to severe plantar flexor spasticity had heel first foot-floor contact pattern when they wore the polypropylene orthosis. None of these subjects had this pattern in the BiCAAL AFO. In the group of 11 patients with absent to minimal plantar flexion spasticity and triceps surae paresis, all persons had heel first initial contact patterns when the polypropylene AFO was worn. Nine of 11 persons had this pattern in the BiCAAL AFO.

When the polypropylene AFO was worn, seven of sixteen persons demonstrated first and fifth metatarsal or first, fifth and great toe foot-floor contact patterns at terminal stance. In the BiCAAL AFO, these characteristic patterns were not noted. When the subgroups of plantar flexion spasticity, were analyzed those persons with absent to minimal increases in tone had four, and those with moderate to severe tone had three of these patterns. No trend existed between the degree of clinical spasticity and the foot-floor contact patterns at terminal stance. The patterns appear to be more dependent on the type of orthosis rather than the degree of plantar flexion tone.

Patient Preference

Of the 17 patients who began this study, three chose not to wear the polypropylene AFO after the initial two week period of accommodation. One subject complained of a burning sensation on the foot and could not tolerate the total limb contact provided by the plastic orthosis. Another stated he preferred the BiCAAL orthosis because he felt unstable while wearing the polypropylene AFO. His velocity and single limb support reflected his feelings of instability. In the BiCAAL orthosis the patient demonstrated a greater percent normal single limb support time (BiCAAL 58 percent; polypropylene 30 percent) and a greater free velocity (BiCAAL 58 percent; polypropylene orthosis had difficulty putting on his shoe over the AFO.

DISCUSSION

The results indicate that a rigid polypropylene orthosis can provide the same ankle stability as a BiCAAL orthosis. No significant differences were noted with respect to gait velocity, cadence, or stride length when either orthosis was used to correct plantar flexion deformity resulting from spasticity or to stabilize the flaccid ankle in the paretic limb.

Patients walking in the polypropylene orthosis had a shorter swing time and spend a greater percentage of the gait cycle in double limb support than when using the BiCAAL orthosis. One possible explanation for the reduced swing time is the light weight of the rigid polypropylene orthosis, 250-400 grams, versus the BiCAAL orthosis weight of 800-900 grams (weight varies slightly because of differences in shoe size, style and amount of material for different sized patients).[12] A more normal pattern of foot-floor contact was observed in patients wearing the rigid polyproylene AFO at initial contact and at terminal stance. When the polypropylene AFO was worn the involved limb was advanced at a faster rate creating greater momentum. This afforded the patients a better opportunity to achieve terminal knee extension and a heel first initial contact foot-floor contact pattern. Significantly greater knee extension at initial contact in the polypropylene AFO as compared to the BiCAAL AFO at free cadence walking demonstrated this factor. Since the velocity of walking is similar in both orthoses, this decrease in swing time in the polypropylene AFO enables this group to devote a greater percentage of the gait cycle to the stance phase of gait. This is reflected in greater initial and terminal double support times. This increase in balance assist time could account for the greater number of normal foot-floor contact patterns occurring during terminal stance in the polypropylene AFO.

Despite the fact that the patients had worn the BiCAAL orthosis a minimum of three months prior to entry into the study, the majority (14 to 17) preferred the rigid polypropylene orthosis. Since our data indicates the rigid polypropylene orthosis can provide the same degree of rigidity as the BiCAAL orthosis, its obvious superiority in terms of weight, cosmesis, and the ability of the patient to interchange shoes with the same heel height makes it the more preferable for most patients for chronic usage.

In our current clinical practice the BiCAAL orthosis is usually prescribed as the initial orthosis for patients with excessive plantar flexion deformity secondary to spasticity or ankle instability in a flail limb. The adjustable ankle feature allows the clinician to determine the optimum ankle position which varies among patients. This feature is also useful if the patient's neurologic condition has stabilized and the optimum ankle position has been determined, the rigid polypropylene orthosis is used as the permanent treatment of choice.

SUMMARY

The lighter polypropylene AFO promotes more efficient advancement of the involved limb, allowing a greater percentage of the gait cycle to be devoted to the stance phase of gait. It was functionally equivalent to its counterpart, and was aesthetically acceptable to the majority of the

stroke patients who participated in this study.

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